

Rosetta End of Mission

# The cometary zoo



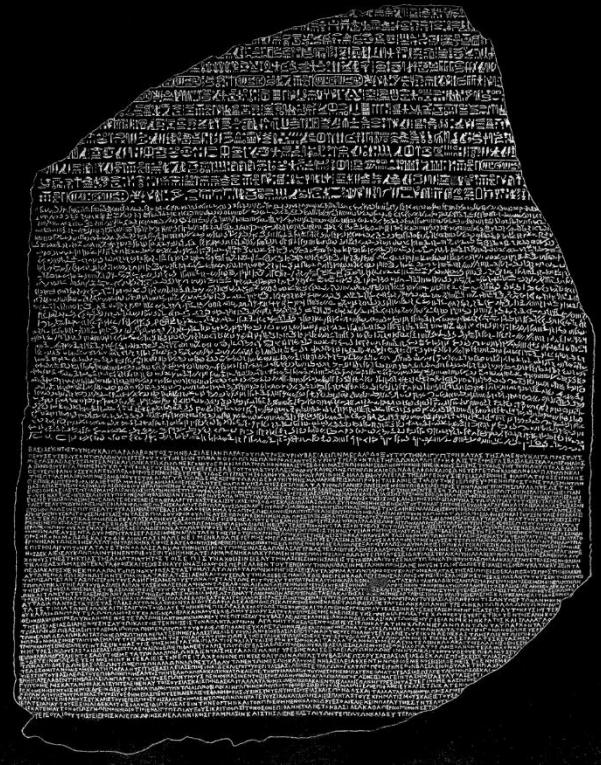
esa

European Space Agency

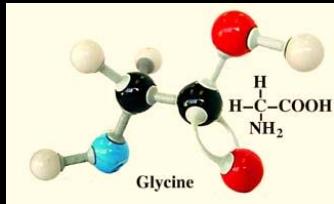
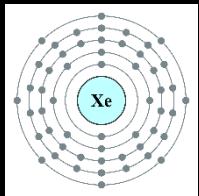
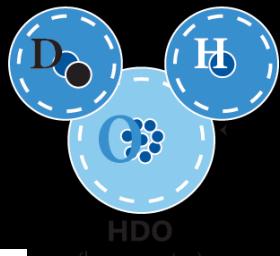
# Deciphering the Rosetta stone

The ultimate goal of  
Rosetta:

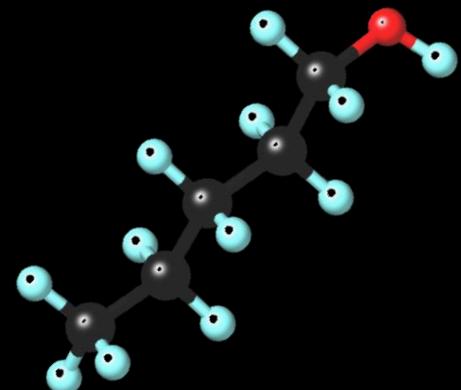
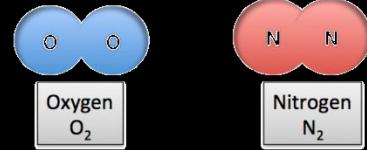
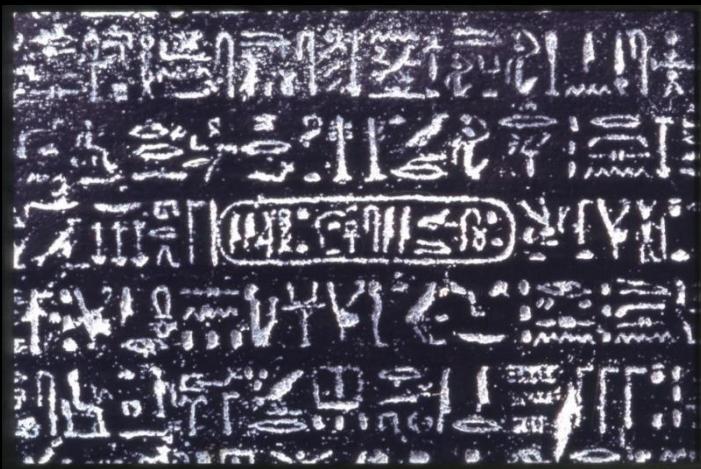
Decipher the origin of the  
solar system, the Earth and  
life by studying a comet



....starting from the chemical composition



Let each species tell its own tale



Interstellar medium



Giant Molecular Cloud



Star forming region



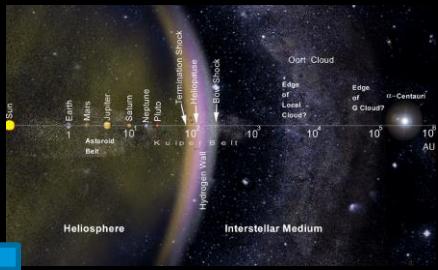
Evolution of the material

Protoplanetary nebula

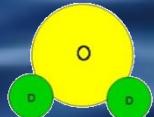
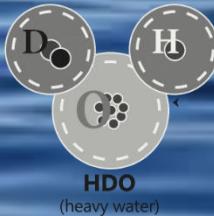
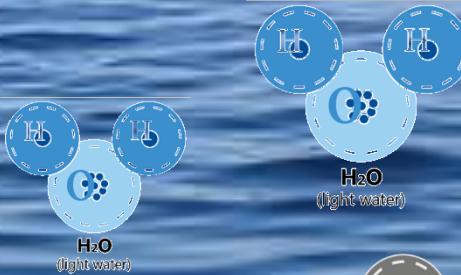
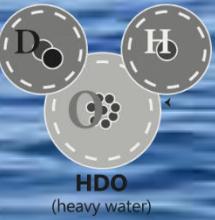
Starting conditions  
Chemistry  
Physical conditions (d, T, t)



Evolution of life



# ROSETTA Zoo



# Deuterated species

## Comet 67 P/C-G

D/H  $\sim 5.3 \cdot 10^{-4}$  in H<sub>2</sub>O

D/H  $\sim 8 \cdot 10^{-4} - 10^{-2}$  in H<sub>2</sub>O

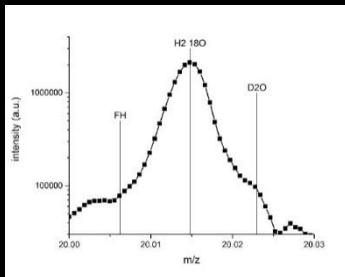
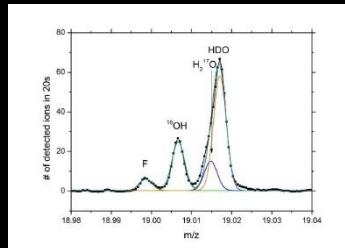
D<sub>2</sub>O / HDO  $\sim 1\%$

## Molecular clouds

D/H  $\sim 8 \cdot 10^{-4} - 10^{-2}$

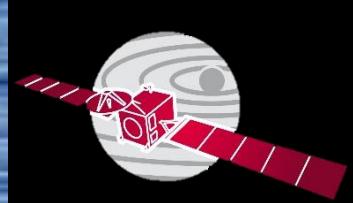
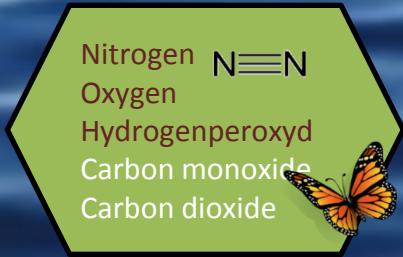
in H<sub>2</sub>O

1.2 %



- Water is inherited from the presolar cloud
- The big variability of D/H in comets points to the fact that they were formed over a large region, that the comet families (Oort cloud, Kuiper belt, etc.) were not formed separately, but just have a dynamically different history
- The Earth did not get the bulk of its water from comets

# ROSETTA Zoo

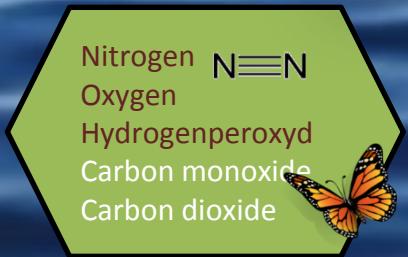
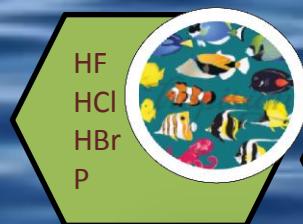
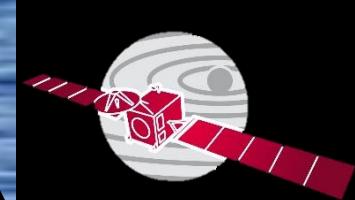


# The presence of highly volatile species tells us



- That comets were never warm
- That comets cannot have been part of a big object (heating by radioactivity)
- That comets formed around 25 K (-250°C)
- O<sub>2</sub> is very puzzling, as it is very reactive. It is very well correlated to water and cannot be formed in the protosolar cloud. Therefore, it's inherited as part of the water ice from the presolar cloud.

# ROSETTA Zoo





## What's the composition of a comet?



Before Rosetta, we thought that....

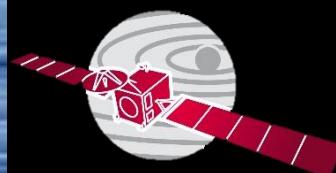
Cometary ice contains simple molecules, which have formed in the gas phase.

- True, but....

The refractory part (dust) is made out of Magnesium, Silicon, Iron, etc.

- True, but....

# ROSETTA Zoo



$S_2$

$S_3$

$S_4$



Methanethiole  
( $CH_3SH$ )

Ethanethiol ( $C_2H_5SH$ )

Thioformaldehyde  
( $CH_2S$ )

Cyanogen  
( $C_2N_2$ )

HF

HCl

HBr

P



Acetylene

HCN

Acetonitrile

Formaldehyde



Nitrogen  $N \equiv N$

Oxygen

Hydrogenperoxyd

Carbon monoxide

Carbon dioxide



Hydrogensulfide

Carbonylsulfide

Sulfur monoxide

Sulfur dioxide

Carbon disulfide



Na, Si, K



# Sulphur inventory of comets



- Interstellar material contains sulphur in cosmic abundance while presolar clouds are mysteriously depleted in sulphur
- Comets contain species which can only be formed on dust grains (e.g.  $S_2$ ,  $S_3$ ,  $S_4$ ...).
- They must have been inherited from the presolar cloud. Therefore, most Sulphur in presolar clouds is on grains which explains the apparent depletion (bias in observation).
- $S_2$  is very volatile and easily destroyed in the gas phase by UV. This means it must have survived the formation of the solar system in the ice.
- Some ice is directly inherited from our native cloud.

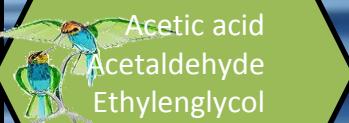
## Macromolecules

Methane  
Ethane  
Propane  
Butane  
Pentane  
Hexane  
Heptane



# ROSETTA Zoo

Formic acid  
Acetic acid  
Acetaldehyde  
Ethylenglycol  
Propylenglycol  
Butanamide



Methanol  
Ethanol  
Propanol  
Butanol  
Pentanol



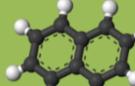
$S_2$   
 $S_3$   
 $S_4$   
Methanethiole  
(CH<sub>3</sub>SH)  
Ethanethiol (C<sub>2</sub>H<sub>5</sub>SH)  
Thioformaldehyde  
(CH<sub>2</sub>S)



Cyanogen  
(C<sub>2</sub>N<sub>2</sub>)



Benzene  
Toluene  
Xylene  
Benzoic acid  
Naphthalene



HF  
HCl  
HBr  
P



Acetylene  
HCN  
Acetonitrile  
Formaldehyde



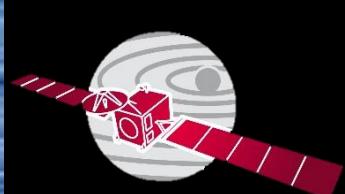
Nitrogen  
Oxygen  
Hydrogenperoxyd  
Carbon monoxide  
Carbon dioxide



Hydrogensulfide  
Carbonylsulfide  
Sulfur monoxide  
Sulfur dioxide  
Carbon disulfide



Na, Si, K



# Hydrocarbons in comets



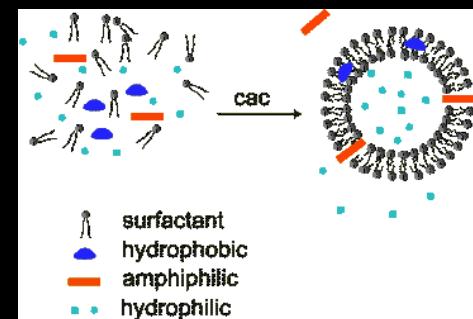
Long carbon chains seen in the volatile part (ROSINA)

Macromolecules (C-H) seen in the dust (COSIMA)

Carbon signature seen on the surface (VIRTIS)

Polyaromatic hydrocarbons detected in the volatile coma (benzene, naphthalene,..)  
(ROSINA)

Prebiotic importance: such chains and rings are needed  
to form the first membrane - like structures



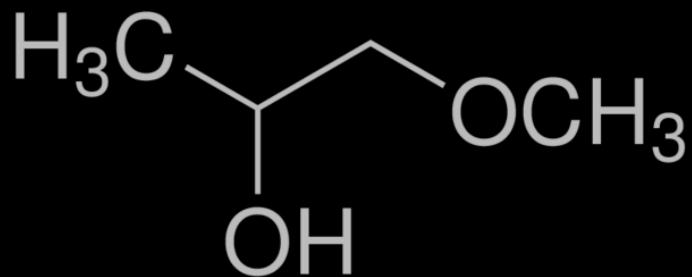
# Complex oxygen bearing compounds



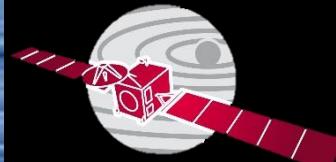
Seen by ROSINA in the coma

Signatures seen on the surface by COSAC and Ptolemy

- More complex than anticipated
- Large amount and diversity
- Prebiotic molecules



# ROSETTA Zoo



Methane  
Ethane  
Propane  
Butane  
Pentane  
Hexane  
Heptane



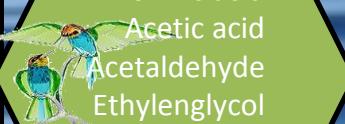
$\text{S}_2$   
 $\text{S}_3$   
 $\text{S}_4$



Ammonia  
Methylamine  
Ethylamine



Formic acid  
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Ethylenglycol  
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Butanamide



HF  
HCl  
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Acetylene  
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Benzene  
Toluene  
Xylene  
Benzoic acid  
Naphthalene

Methanol  
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Propanol  
Butanol  
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Nitrogen  $\text{N}\equiv\text{N}$   
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Na, Si, K



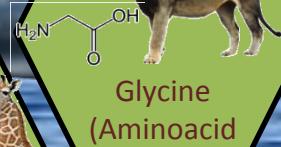
# Comets do not contain life



# ROSETTA Zoo



Methane  
Ethane  
Propane  
Butane  
Pentane  
Hexane  
Heptane



$S_2$

$S_3$

$S_4$



Methanethiol ( $CH_3SH$ )

Ethanethiol ( $C_2H_5SH$ )  
Thioformaldehyde ( $CH_2S$ )



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Cyanogen ( $C_2N_2$ )



Benzene  
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Naphthalene



HF

HCl

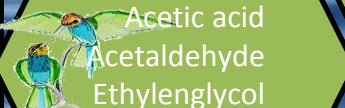
HBr

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Nitrogen  $N \equiv N$   
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Carbon disulfide



Na, Si, K





# Did comets bring the Earth atmosphere (and as a consequence organic material)?

The answer is probably hidden in the noble gases of 67P

- Argon of 67P is compatible with a delivery of the terrestrial atmosphere by comets (late heavy bombardment) without changing the D/H in water.
- The Xenon in the Earth atmosphere is not understood. It seems to contain a primordial source (U-Xenon), which has never been found. Is the Xenon in 67P this U-Xenon? (analysis ongoing)

Interstellar medium



Giant Molecular Cloud



Star forming region



Protoplanetary nebula



Evolution of life

Xenon isotopes  
Silicon isotopes

Sulphur

O<sub>2</sub>, S<sub>2</sub>  
D<sub>2</sub>O

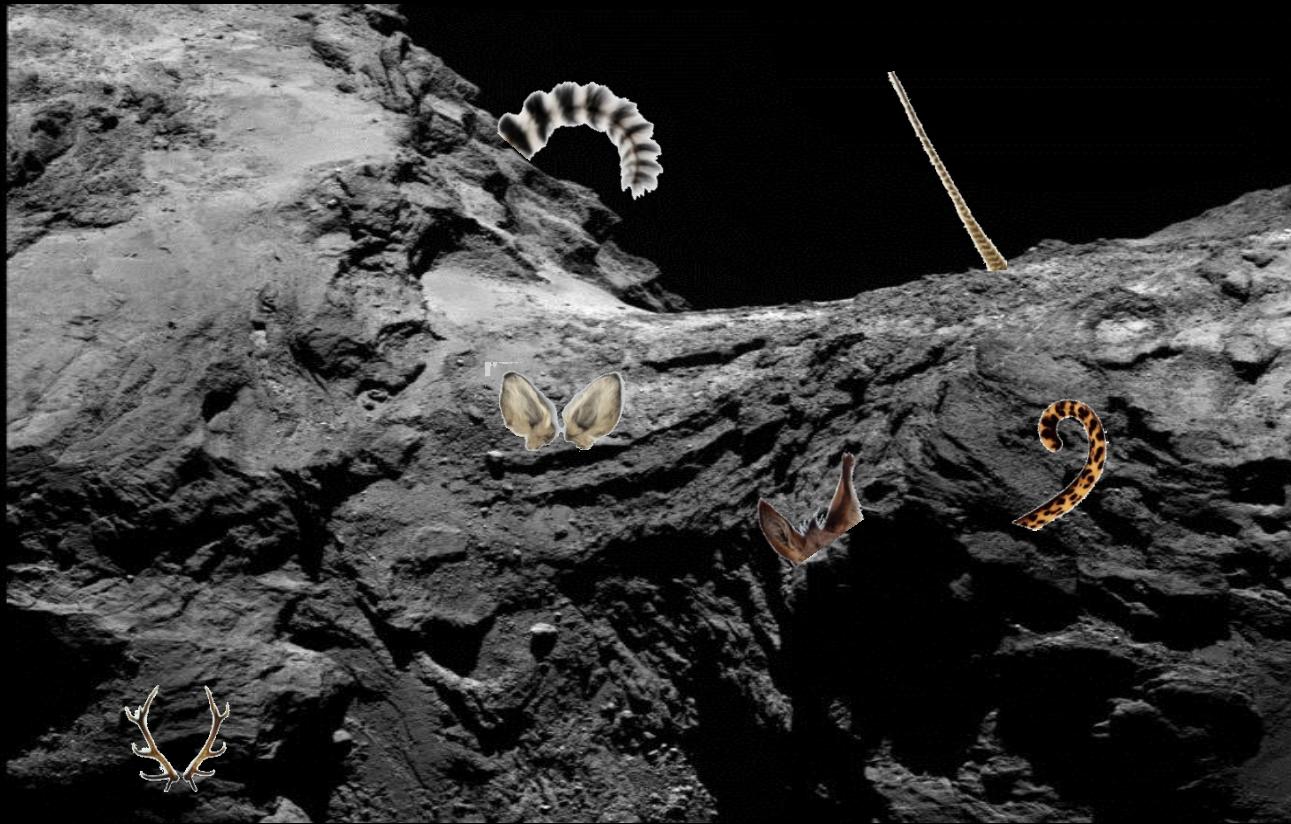
Noble gases,  
organics

D/H in  
water

CO, Ar,  
CH<sub>4</sub>



# Some more animals on the horizon, more tales to tell..



European Space Agency

Each species is telling it's own tale  
.....more stories in the coming years  
.....stay tuned



European Space Agency